WEHRSTEDT

Voids in Sands
and Broken Stone

Civil Engineering

B. S.

1900
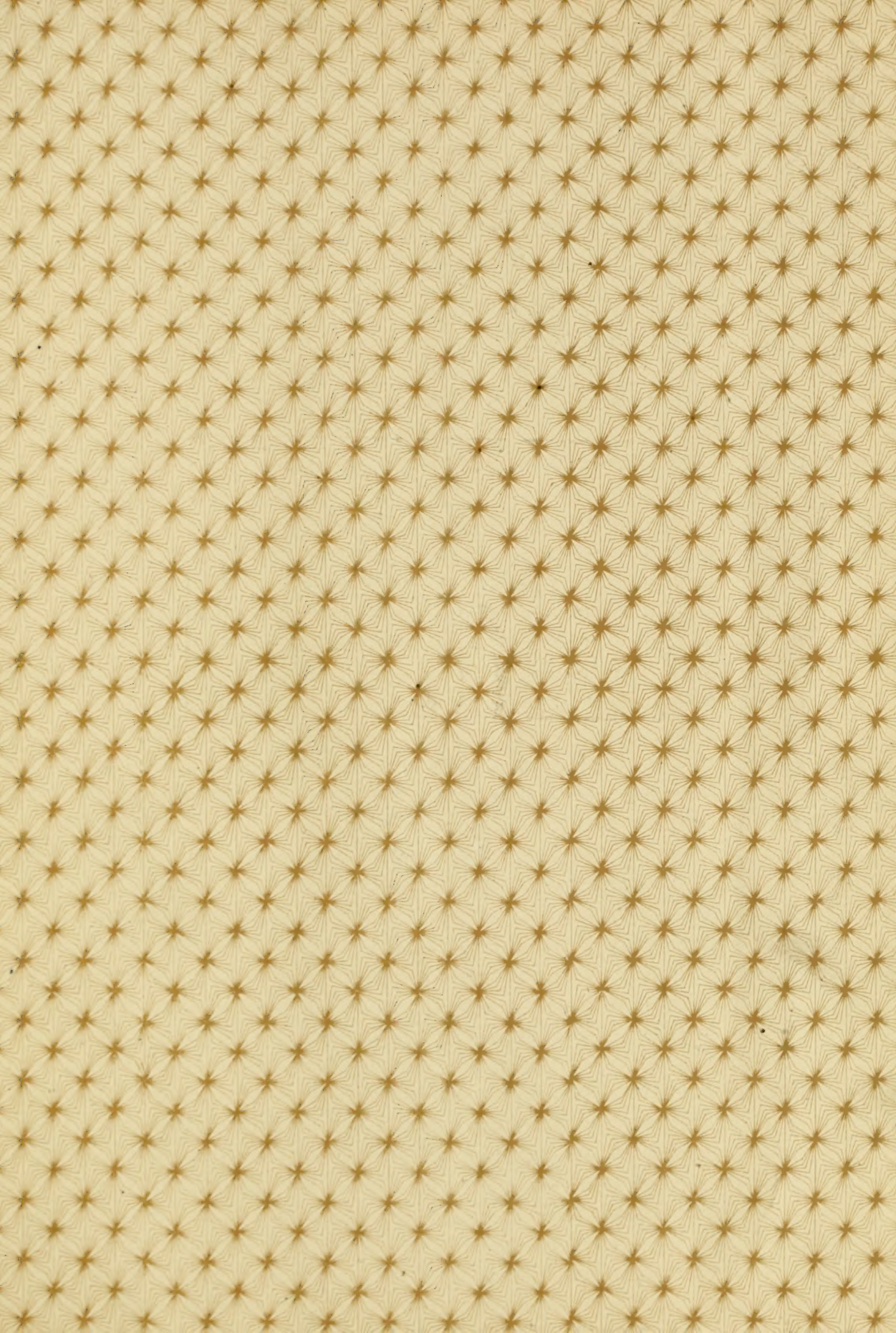
Voids in Sand

and

Broken Stone

BY

Otto Charles Wehrstedt

THESIS

FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1900

UNIVERSITY OF ILLINOIS

.........................May 31, 1900.......... 190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Otto Charles Wehrstedt

ENTITLED Voids in Sand and Broken Stone

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering.

Ira O. Baker

HEAD OF DEPARTMENT OF Civil Engineering.

Voids in Sand and Broken Stone.

Introduction.

In mixing sand and cement in making mortar, and gravel or broken stone and cement in making concrete, the usual method of proportioning has been by volumes, that is, a certain volume of aggregate to a certain volume of cement, the proportions giving the supposedly best results having been determined from practice.

Now in the case of two kinds of broken stone of the same volume, the voids in the one being much greater than the voids in the other, it is self evident that to get the same strength from both the former must contain more mortar than the latter. If the ingredients are proportioned by volumes, each concrete will have the same proportions, since the volumes are the same. Now if this proportion is correct for one kind of stone, there will be either an excess or a defi-

measured out in a vessel of known capacity. The sand was then emptied out. Water and the measured volume of sand were then poured in the vessel in successive increments, the water being kept continually above the sand. By pouring the sand through the water, the air bubbles were practically eliminated. The sand was allowed to fall only a short distance, about a foot, because if it fell a greater distance the larger and heavier grains would become separated from the lighter ones and go the bottom, thus increasing the voids. After all the sand had been added water was added sufficiently to fill the vessel. The volume of the water used, divided by the volume of the sand (the total capacity of the vessel) gives the per cent of voids.

By the above method the voids in the first column under Voids of Table I were found.

In finding the voids in the rammed volume (second column in Table I under Voids) the process was similar
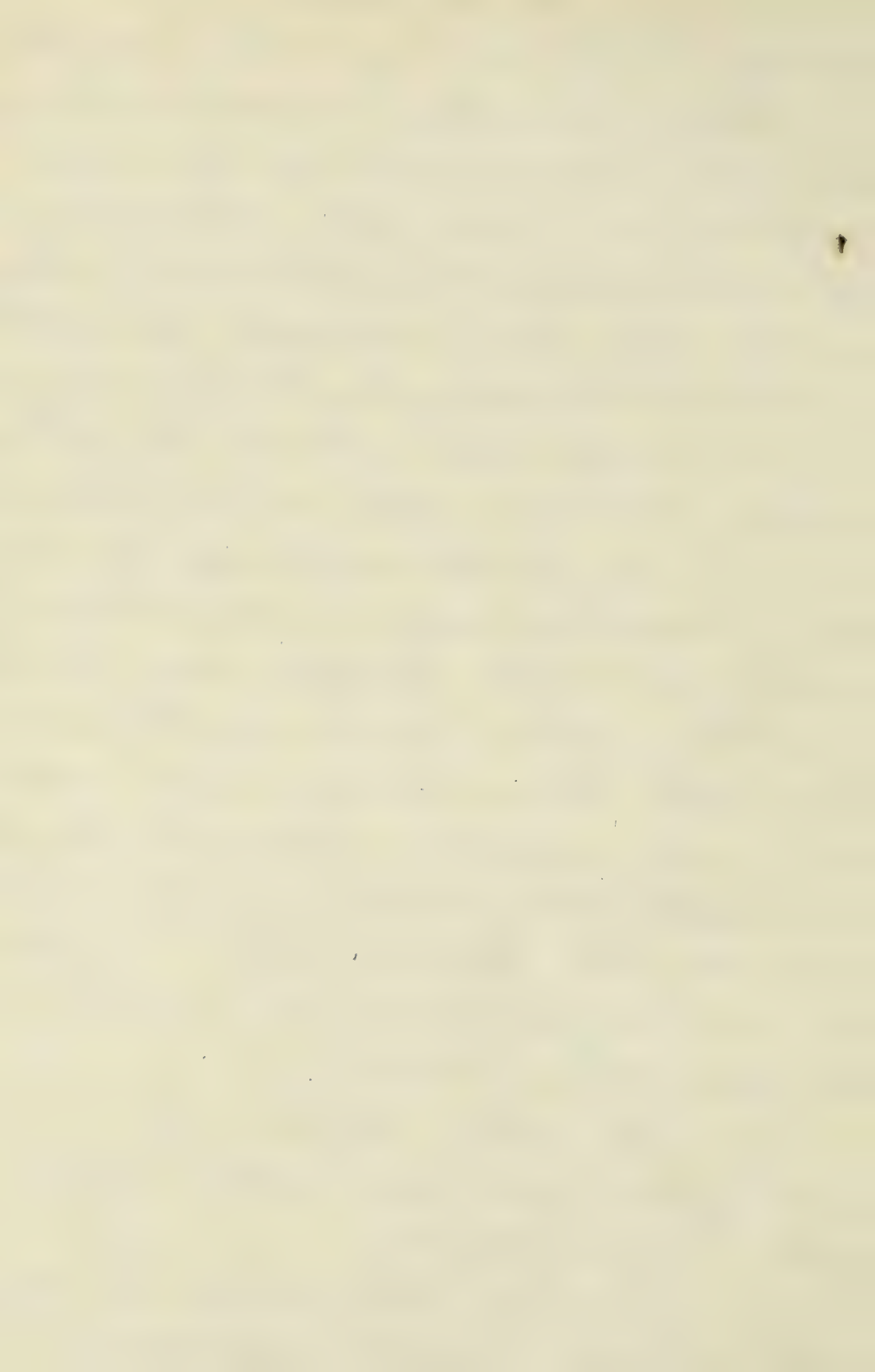
to the above except that the volume of the sand was not measured out beforehand, the volume being the volume of the wet, rammed sand (equal to the capacity of the vessel.)

When a small amount of moisture is evenly distributed throughout the sand, the volume is considerably increased. Prof. I. O. Baker says* that "sand with two per cent of moisture has nearly twenty per cent greater volume than the same sand when perfectly dry". However when the sand is saturated with water the volume is less than when dry. In the third column under Voids in Table I, the writer tabulated the voids in the rammed volume in terms of the loose volume. This gives the amount of water, in per cents of the volume loose, to be added to the loose, dry volume, to just fill the voids in the sand when wet and rammed.

The method of determining this was to measure out a volume of loose sand, and then add and ram the successive

* Masonry Construction, 9th ed., p. 79.

increments of sand in the water. Since the wet, rammed volume of sand was less than the dry, loose volume, the sand did not entirely fill the vessel and the water was not brought level with the top of the vessel but just even with the top of the sand. Then the amount of water used, divided by the capacity of the vessel gives the voids in the rammed sand in terms of the volume of the loose sand.

The voids in the broken stone were determined the same as in the sand. Since the dry stone absorbs more or less water, dry stone would give a larger per cent of voids than wet. Some stones also absorb more water than others. Therefore the stones were all saturated before the voids were determined, so that there would be a uniform basis for comparison, and so that the water added would represent only the voids or interstices.

The voids in broken stone are given in Table II.

TABLE I

FINENESS AND VOIDS OF BUILDING SANDS.

Arranged in order of Per Cent of Voids.

Ref. No.	Description	Fineness							Voids, Per Cent of,			Weight Lbs per cu.ft.	
		Per Cent, by weight caught on Sieve No.						Per Cent passing No.100	Volume Loose.	Volume Rammed.	Volume Rammed in Terms of Volume Loose.	Dry Loose	Dry Rammed
		5	20	30	50	75	100						
1	1899 unsifted	2	34	16	24	23	0	1	39	29	24	84	97
2	1900 unsifted	0	23	12	29	31	5	0	45	31	24	79	81
3	1900 sifted	0	100	0	0	0	0	0		33			
4	" "	0	0	100	0	0	0	0		34			
5	" "	0	0	0	100	0	0	0		34			
6	" "	0	0	0	0	100	0	0		34			
7	" "	0	0	0	0	0	100	0		33			
8	" "	0	67	0	0	0	33	0		27			
9	" "	0	20	20	20	20	20	0		29			
10	" "	0	75	0	0	0	25	0		30			
11	Streator, Ill.	0	7	6	22	48	9	8	40	33	30	85	95
12	German Standard.	0	0.5	95	4	0.5	0	0	40	35	33	93	100
13	Lake Michigan, Chicago.	0	2	3	13	62	20	0	43	40	34	98	108
14	Crushed Quartz.	0	15	79	5	1	0	0	51	43	37	90	100

Stipes's Bank, Urbana Ill (Ref. Nos. 3–10)

TABLE II

FINENESS AND VOIDS OF BROKEN STONE.

Arranged in order of Per Cent of Voids.

Ref. No.	Description	Fineness			Per Cent passing ½"	Voids, Per Cent of Volume		Weight Lbs. per cu. ft.
		Per Cent, by weight, not passing ring having diameter of				Loose	Rammed	Loose.
		2"	1"	½"				
1	Flint	0	38	51	11	44	38	76
2	Granite	0	0	6	94 *	45	39	85
3	Sandstone	0	97	3	0	47	40	73
4	Limestone	10	51	31	8	47	39	85
5	"	0	0	100	0	44	38	78
6	"	0	100	0	0	48	42	76
7	"	100	0	0	0	53	47	
8	"	20	20	40	20	37	35	
9	"	20	30	30	20	40	30	
10	"	67	33	0	0	46	41	
11	"	20	40	40	0	48	42	

* 74% caught on Sieve No.5, 20% passing No.5.

Discussion of the Results.

An examination of lines 3-7 of Table I shows that the per cent of voids is practically independent of the size of grains. Some writers claim that the finer sand gives the lesser per cent of voids. Possibly the slight difference in voids is due to the form of grains. The larger grains are more irregular and do not fit so closely together as the finer, and hence the percentage of voids is somewhat larger. Generally speaking the proportion of voids is independent of the size of the grains, but it is affected by the variation or gradation of sizes. Prof. I. O. Baker says;[*] "A mass of perfectly smooth spheres packed together as closely as possible contains twenty-six per cent of voids; but if the spheres are packed as loosely as possible, the voids would be forty-six per cent. A promiscuous mass of bird shot contains about thirty-six per cent of voids. The difference between this and the theoretical minimum per cent is due to the variation in size, to roughness of the

---

[*] Masonry Construction, 9th ed., p. 794.

surface, and to not securing in all parts
of the mass the arrangement of the shot
necessary for minimum voids."

Lines 8, 9 and 10 show the results of
an attempt to make an artificial mix-
ture of sand having minimum voids.
Notice that equal per cents of the var-
ious sizes gave 29 per cent voids —
the same as the unsifted sand (see line 1).
"If the grains are spherical and the
diameter of the smaller is about one
fifth of the diameter of the larger,
the smaller grains will just fit the inter-
stice between the larger ones".* This limits
the amount by which the voids may
be reduced, since with a a No. 20 sand
the next smaller size to be used to just
fill the interstices would have to be a
No. 100 sand. For the finer sands it
would be impossible to get grains small
enough to just fill the interstices. Since
the variation in the size of the grains of
sand is not great enough, it is not pos-
sible to so proportion the sizes that the
smaller grains will just fit the voids in

* Baker's Masonry Construction, 9th ed., p. 79j.

the larger ones. The best results were obtained with a proportion of 67 per cent of No. 20 sand, and 33 per cent of No. 100 sand (see line 8 of Table I). It would not be practicable to use this proportion for ordinary purposes.

An inspection of Table II also shows that the broken stone having pieces of nearly one size give a larger per cent of voids than that containing a variety of sizes. For example, line 7 shows that broken stone screened to practically one size has 47 per cent voids, while line 9 shows that a variety of sizes gives 30 per cent voids, or only about two thirds as much as screened stone. It is quite common in practice to specify screened broken stone. The above investigation shows that screend stone requires approximately 50 per cent more mortar to fill the voids than un screened. Current practice could be materially improved in this respect, since it is much cheaper to fill the voids with small fragments of stone than with cement mortar.
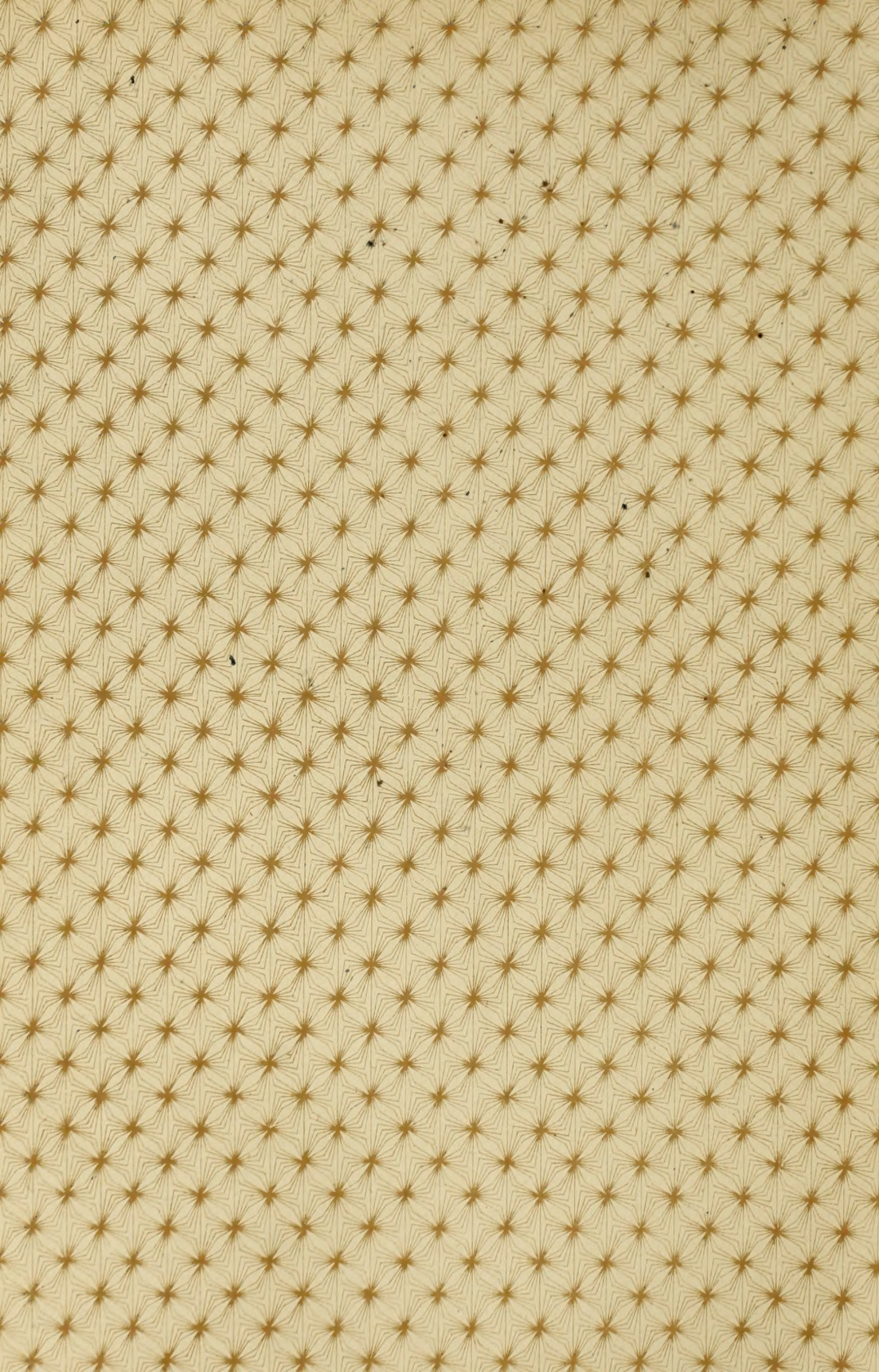
Conclusion.

The preceding shows the method of determining the voids in sand, gravel and broken stone, and Tables I and II show the variation of the voids with the fineness of the materials. To proportion mortar and concrete scientifically, it is necessary to know at least approximately the per cent of voids in the sand and broken stone. A suggestion has been made showing how the ordinary practice of making concrete can be improved so as to secure both greater strength and less cost.